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ABSTRACT

This paper considers whether "liquidity trap" issues have important bearing on the desirability of inflation targeting as a strategy for monetary policy. From a theoretical perspective, it has been suggested that "expectation trap" and "indeterminacy" dangers are created by variants of inflation targeting, the latter when forecasts of future inflation enter the policy rule. This paper argues that these alleged dangers are probably not of practical importance. From an empirical perspective, a quantitative open-economy model is developed and the likelihood of encountering a liquidity trap is explored for several policy rules. Also, it is emphasized that, if the usual interest rate instrument is immobilized by a liquidity trap, there is still an exchange-rate channel by means of which monetary policy can exert stabilizing effects. The relevant target variable can still be the inflation rate.

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1. Introduction

The purpose of this paper is to consider whether issues regarding "liquidity trap" or "zero lower bound" phenomena substantially affect the case for inflation targeting, in comparison to other possible strategies for conducting monetary policy. The paper takes up both theoretical and empirical issues, and in the latter case emphasizes the importance of an economy's openness to foreign trade in goods and securities.

The first theoretical topic to be investigated is prompted by recent papers by Benhabib, Schmitt-Grohe, and Uribe (1998), Dupor (1999), and Schmitt-Grohe and Uribe (2000), among others, which argue that recognition of the existence of a zero lower bound (ZLB) on nominal interest rates leads to the conclusion that inflation targeting rules—or ones of the more general Taylor (1993a) type—are likely to fail. The alleged reason is that the existence of a ZLB implies that rational expectations (RE) solutions to standard optimizing models with Taylor rules are not unique and one solution, likely to be attained, involves a deflationary liquidity trap. It is the contention of the present paper that this alleged danger should not be considered to be of substantial practical importance. This argument is developed in Section 2.

Next, in Section 3 the paper takes up a closely related topic concerning the danger of solution "indeterminacy" that, according to Woodford (1994) and several other analysts, is generated by the practice of basing policy actions on expected future inflation rates, rather than on currently-observed values. Again, and for similar reasons, it is here argued that the danger is probably illusory.

The foregoing points are of a theoretical and general nature, so they can be discussed in the setting of a highly stylized and extremely simplified theoretical framework. When one turns to empirically-oriented issues, however, it becomes important to work with a model that reflects more closely the properties of actual economies. Consequently, an open-economy model with slow price level adjustments and inertia in consumption demand is specified in Section 4. Quantitative calibration is undertaken in Section 5 and some aspects of the model's properties are presented.

In Section 6 the foregoing model is utilized to examine the frequency, under alternative policy rules, of occasions on which zero or negative interest rates are encountered in stochastic simulations designed to mimic realistic conditions. In this manner, some indication is provided of the relative frequency with which liquidity trap situations may arise under inflation targeting, in comparison with other policy rules.

Then in Section 7 it is assumed that the economy is in a liquidity trap situation, so that the (usual) interest rate instrument is immobilized. The possibility of using monetary policy for stabilizing purposes nevertheless is provided by the existence of a transmission channel involving foreign exchange. In Section 7 the relative potency of this channel with an inflation targeting objective is examined quantitatively. Some authors have contended that this exchange rate channel is not available because of the relationship known as uncovered interest parity; consequently their contentions are taken up and strongly disputed. Section 8 provides a brief concluding summary.

Before beginning with these various topics, it is necessary to mention the way in which the term "inflation targeting" is used in this paper. Specifically, an inflation targeting regime is taken to be one in which monetary policy is conducted according to a rule[1] that specifies adjustments of an instrument variable in response to deviations of

[1] Of course, it is not being supposed that any actual central bank would ever follow literally the instructions of any simple formula. But for analytical purposes we need to focus attention on the systematic aspects of

inflation, or expected future inflation, from a policy-specified target value. With this conception, are responses to other variables, such as the output gap term in Taylor-style rules, permitted? Here no particular position will be taken on that terminological issue; instead we will simply refer to such cases as reflecting departures from pure inflation targeting. Also, responses to previous-period values of the instrument variable are permitted so as to reflect "smoothing" behavior of a type that seems to be widely practiced by actual central banks.

I am of course fully aware that Svensson (1997, 1999) has argued for a different terminological convention, one that would use the word "target" only to refer to variables that appear in explicitly specified loss functions. But it is often useful to proceed without adoption of any explicit loss function. In fact, I believe that my terminology is more consistent with actual practice, in part because actual central banks have thus far not adopted explicit loss functions. In any event, the issue is of little importance, especially since it always possible to write instrument rules that approximate as closely as desired the instrument settings of a policy regime involving targeting in Svensson's sense.

2. An Expectational Liquidity Trap?

As mentioned above, Benhabib, Schmitt-Grohe, and Uribe (1998) and others have suggested that Taylor-style rules, of which inflation targeting (IT) rules provide a special case, are perilous in the sense that they may induce the economy to enter a deflationary liquidity trap.[2] In a previous paper (2000a), I have briefly argued that this outcome is

monetary policy, and these can be clearly expressed in terms of a rule. I will not be attempting to find an "optimal" rule, for any such finding would be highly model-specific, so I do not need to discuss commitment issues. With regard to the "rules versus discretion" question, however, I would note that it is also implausible that any actual central bank would ever follow literally the instructions of an optimal control exercise repeated anew each decision period.

[2] The trap discussed by Reifschneider and Williams (2000) and Krugman (1998) is similar in some respects, but involves a different mechanism as the models utilized are entirely backward-looking.

highly unlikely; that the danger is a theoretical curiosity that should not be considered relevant for practical policy analysis. Here that argument will be developed considerably more fully.

For the purpose of this purely analytical investigation, it will be sufficient to use a closed-economy model with full price flexibility. An extremely simple but adequate framework is provided by the following two-equation system:[3]

(1) $y_t = b_0 + b_1(R_t - E_t\Delta p_{t+1}) + E_t y_{t+1} + v_t$

(2) $R_t = \mu_0 - \mu_1\pi^* + (1 + \mu_1)\,\Delta p_t + \mu_2\, y_t.$

Here y_t and p_t denote the logs of output and the price level so Δp_t is inflation and R_t is the one-period nominal interest rate. Equation (1) represents a log-linearized expectational IS function, which describes aggregate demand behavior in a fashion that can be rationalized by dynamic optimizing analysis as explained by Woodford (1995, 2000), McCallum and Nelson (1999), and many others. The term v_t represents a taste shock that is generated by an exogenous stochastic process, which is assumed to be AR(1), i.e., autoregressive of order one, with parameter ρ. Equation (2) is a Taylor rule in which the central bank is depicted as setting an interest rate instrument R_t each period so as to tighten policy when inflation exceeds its target value π^* and/or when output is high. In (2), y_t should be interpreted as the output gap, $y_t - \bar{y}_t$, with $\bar{y}_t$ for simplicity assumed constant at the value zero. For present purposes, furthermore, we are treating prices as fully flexible so we have $y_t = 0$ in each period. Thus there are only two endogenous variables in the system, R_t and Δp_t. This model should be understood to also include the

[3] This is essentially a linearized version of the first model used by Benhabib, Schmitt-Grohe, and Uribe.

requirement that Δp_t must not approach $-\infty$ as $t \rightarrow \infty$, which represents a transversality condition that obtains in the underlying optimizing model.[4]

To obtain a rational expectations (RE) solution, we first substitute out R_t and using $y_t = 0$ obtain

(3) $\quad 0 = b_0 + b_1[\mu_0 - \mu_1\pi^* + (1 + \mu_1)\Delta p_t - E_t\Delta p_{t+1}] + v_t.$

The minimum state variable (MSV) solution is of the form

(4) $\quad \Delta p_t = \phi_0 + \phi_1 v_t,$

implying $E_t\Delta p_{t+1} = \phi_0 + \phi_1\rho v_t$. Then substitution into (3) and application of the undetermined coefficient procedure yields the requirement that

(5) $\quad 0 = b_0 + b_1[\mu_0 - \mu_1\pi^* + (1+\mu_1)(\phi_0 + \phi_1 v_t) - \phi_0 - \phi_1\rho v_t] + v_t$

holds identically for all realizations of v_t. That implies unique values for ϕ_0 and ϕ_1 and gives the MSV solution

(6) $\quad \Delta p_t = \pi^* - (b_0 + b_1\mu_0)/\mu_1 - [b_1(1-\rho+\mu_1)]^{-1}v_t.$

Of course, Taylor (1993a) and many others prescribe that the central bank set $\mu_0 = r$, the long-run average real rate of interest. and we observe from (1) that this rate is $-b_0/b_1$. So adherence to this recommendation implies that the second term on the right-hand side of (6) vanishes and we have $\Delta p_t = \pi^* - [b_1(1-\rho+\mu_1)]^{-1}v_t$ as the MSV solution for inflation. Since the unconditional expectation $E(v_t) = 0$, it is clear that $E\Delta p_t = \pi^*$, i.e., the long-run average rate of inflation is equal to the target value specified by the central bank's policy rule.

There is, however, another solution that satisfies the usually-stated conditions for a RE equilibrium. Consider the candidate solution

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[4] See, e.g., Woodford (2000, Ch. 2).

(7) $\Delta p_t = \phi_0 + \phi_1 v_t + \phi_2 \Delta p_{t-1}$,

which implies $E_t\Delta p_{t+1} = \phi_0 + \phi_1\rho v_t + \phi_2(\phi_0+\phi_1+v_t+\phi_2\Delta p_{t-1})$. Then, presuming $\mu_0 = -b_0/b_1$, the undetermined coefficient conditions are

(8a) $b_1[-\mu_1\pi^* + (1+\mu_1)\phi_0 - \phi_0(1+\phi_2)] = 0$

(8b) $b_1[(1+\mu_1)\phi_1 - \phi_1\rho - \phi_2\phi_1] + 1 = 0$

(8c) $\phi_2^2 = \phi_2(1 + \mu_1)$.

Thus there are two possibilities for ϕ_2, 0 and $1+\mu_1$. If the former is selected we have the same MSV solution as in (6), but if $\phi_2 = 1+\mu_1$ is designated as relevant, the solution becomes

(9) $\Delta p_t = -\mu_1 \pi^* + (1+\mu_1)\Delta p_{t-1} + (b_1\rho)^{-1}v_t$.

Clearly, with $\mu_1 > 0$ the latter is explosive. Consequently, if the system "begins" with $\Delta p_{t-1} > \pi^*$ then inflation will increase explosively, and if the startup value is below π^* then Δp_t will <u>tend</u> to approach $-\infty$, according to (9) and as illustrated in Figure 1.

But the last statement ignores the existence of a ZLB on the nominal interest rate. In the flexible price system at hand, the latter translates into a lower bound on Δp_t; we have the restriction $\Delta p_t \geq -r$. Thus if the system begins with $\Delta p_{t-1} < \pi^*$, inflation cannot behave as specified by (9). Instead, the alleged outcome is that $\Delta p_t \rightarrow -r$, which corresponds to $R_t \rightarrow 0$. So in this case the policy rule (2) fails to stabilize inflation around its target value, π^*. This is the failure of the Taylor rule proposed and emphasized by the writers mentioned above.

In McCallum (2000), I argue that the foregoing is a pseudo problem; that the solution just described is most likely not economically relevant. The argument there is that (6) provides the MSV or fundamentals solution whereas (9) represents a RE bubble, and that there is reason to be dubious that bubble solutions are of empirical relevance—at least from a macroeconomic perspective. Here the agenda is to extend that argument by adding another reason to ignore the non-MSV solution, a reason based on the closely related concepts of E-stability and least-squares learnability.

Iterative E-stability was developed in the 1980s, principally by Evans (1985, 1986), and then modified in response to work by Marcet and Sargent (1989). Iterative E-stability involves a thought experiment in which one conceives of expectational behavior with anticipated variables such as Δp^e_{t+1} being described by an expression of a form that would be appropriate under RE, but with parameter values that are initially incorrect.[5] This "expectation function" implies, when substituted into the model of the economy, a law of motion that entails systematic expectational errors. So one can then conceive of revised values of the parameters of the expectation function that are suggested by the law of motion. These too will imply incorrect forecasts, but one can imagine continuing with a series of iterations and consider whether they will converge to a specific RE solution, be it the MSV or a non-MSV solution.[6] If such a process converges to a particular solution, then the latter is said to be iteratively E-stable.

By considering ever-smaller "time periods" for these iterations one can develop a process that is continuous in notional time (meta-time). Evans and Honkapohja (1999, 2000) emphasize this refined notion of E-stability because it is, under fairly general conditions, equivalent to <u>learnability</u> by means of a least-squares-based adaptive process. For a useful introduction to E-stability and learnability, see Bullard and Mitra (2000).

[5] Here Δp^e_{t+1} denotes the subjective expectation of Δp_{t+1} formed at time t, not necessarily according to RE.
[6] If there is convergence, it will be to some RE solution.

The model at hand, summarized in (3), was analyzed by Evans (1986), who found the MSV solution to be E-stable and the bubble solution to be E-unstable. These results extend to the refined definition of E-stability and therefore imply that the MSV solution is least-squares learnable and the non-MSV is not—see Evans and Honkapohja (2000, Section 9.7).

The foregoing statement applies literally to the model without the ZLB constraint. But the latter does not affect the analysis, which is local in nature, of the MSV solution. Then for the non-MSV solution, we need to replace (3) with the ZLB constraint. This can be done by rewriting (3) so as to pass through the point (-r, -r) and inserting a parameter that controls its slope. Then the constraint would be imposed by letting the slope approach zero. Thus the analysis would be as before, but with a slope of less than 1.0 at the non-MSV point, which would not yield E-stability.

A more satisfying approach might be to recognize that the lower bound on the nominal interest rate is actually the consequence of a decreasing net marginal benefit, via facilitation of transactions, provided by holdings of money.[7] Then the relevant functional form would be as illustrated in Figure 2. There the MSV solution is at point A and the liquidity trap at point B. For this continuous nonlinear case, the analysis in Section 11.5 of Evans and Honkapohja (2000) establishes that the MSV solution is E-stable and the trap solution is not.

In sum, there are several reasons to believe that MSV solutions generally prevail in actual economies. In that case, there is no particular reason to believe that a liquidity trap situation would be generated, in the manner under discussion, by the adoption of a Taylor rule or the special case of pure inflation targeting.

3. Is Indeterminacy a Problem for Inflation Forecast Targeting?

An issue closely related to the one just discussed pertains to policymaking in accordance with a rule for inflation forecast targeting, i.e., a rule of the form

(10) $R_t = \mu_0 + E_t\Delta p_{t+1} + \mu_1(E_t\Delta p_{t+j} - \pi^*) + \mu_2 y_t$

with $j \geq 1$. In practice, this is evidently the way that actual inflation targeting regimes have been operated, due to the perceived need for central banks to behave preemptively—i.e., adjusting policy instruments to combat inflationary (or deflationary) pressures before measured inflation (or deflation) begins to show up strongly in measured data.[8] But several analysts, beginning with Woodford (1994), have argued that when $j \geq 1$ in (10) there is a danger of indeterminacy induced that is not present if the policy rule is of the form (2).[9] Note in this regard that for very large values of μ_1, in a policy rule like (10), the implied policy is virtually the same as exact targeting of an expected inflation rate, as promoted by Svensson (1997) and others. Thus the argument seems to deserve scrutiny. Again it will here be suggested that the danger identified by the line of analysis in question represents a theoretical curiosity that is probably not of practical relevance.

It will be necessary to begin the discussion by noting the way in which the term "indeterminacy" is used in this body of literature. That term first became prominent in monetary economics from a series of writings by Patinkin—beginning with (1949) and

[7] See McCallum (2000a).
[8] On the need for preemptive policymaking, see Goodfriend (1997). For descriptions of practices of the Bank of England, Reserve Bank of New Zealand, and Bank of Canada, see King (1999), Archer (2000), and Freedman (2000).

[9] Other papers that have promoted this idea, or discussed it with apparent approval, include Bernanke and Woodford (1997), Kerr and King (1996), Clarida, Gali, and Gertler (1997), Svensson (1997), Christiano

culminating with (1961) and (1965)—that grew out of observations made by Lange (1942) about a putative logical inconsistency in classical monetary theory. Some of Patinkin's conclusions were disputed in a notable book by Gurley and Shaw (1960), and the resulting controversy was prominently reviewed in an influential survey article by Johnson (1962). In all of this earlier literature, it should be noted, the form of indeterminacy under discussion was "price level indeterminacy" such that the models in question fail to determine the value of any nominal variable, including the money supply. That type of failure occurs basically because of postulated policy behavior that is entirely devoid of any nominal anchor—i.e., there is no concern by the central bank for nominal variables.[10] Since rational private households and firms care only about real variables, according to standard neoclassical analysis, the absence of any "money illusion" by them and by the central bank must imply that no agent (in the model) has any concern for any nominal variable. Thus there is in effect no nominal variable appearing anywhere in the model, so naturally it can not determine the value of such variables.

The type of indeterminacy under discussion in the current literature cited at the beginning of this section is very different. Instead of a failure to determine any nominal variable (without any implied problematic behavior for real variables), the recent Woodford-warning[11] literature is concerned with a multiplicity of stable equilibria in terms of real variables.[12] This type of aberrational behavior stems not from the absence of any nominal anchor (a static concept) but from the (essentially dynamic) fact that

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and Gust (1999), Carlstrom and Fuerst (2000), Isard, Laxton, and Eliasson (1999), and Bullard and Mitra (2000).

[10] See Patinkin (1965, p. 309).

[11] This term is due to Lars Svensson.

[12] It is dynamically stable equilibria that are relevant, because explosive paths of real variables are normally ruled out by transversality conditions that show them to be suboptimal for individual private agents.

various paths of real money balances can be consistent with rational expectations under some circumstances.[13]

As an example of the sort of confusion that can arise if the foregoing distinction is not recognized, consider the analysis of "price level indeterminacy" under an interest rate rule developed in the famous JPE paper by Sargent and Wallace (1975). It has long been my belief that this paper was concerned with nominal indeterminacy—see McCallum (1981, 1986). Woodford (2000, Ch. 2), by contrast, interprets this particular Sargent and Wallace discussion as pertaining to solution multiplicity. My position is strengthened by the fact that the only substantive reference cited by Sargent and Wallace is Olivera (1970), which is clearly concerned with nominal indeterminacy. But, in any event, the Sargent-Wallace (1975) paper and the writings that have followed illustrate clearly the importance of observing the distinction.

Let us now consider the substance of the Woodford warning of multiple solutions when policy is based on rational forecasts of future inflation.[14] It can be illustrated in a model similar to our prototype (1)-(2) presented above. For convenience, let us rewrite the model here, but adding a gradual price adjustment relationship. Also, let us now ignore constant terms that are tedious and for present purposes uninteresting. Finally, let us suppose that $E_t\Delta p_{t+1}$ is the inflation-forecast variable to which the policy rule pertains. Then the system can be written as

(11) $y_t = b_1(R_t - E_t\Delta p_{t+1}) + E_t y_{t+1} + v_t$

(12) $\Delta p_t = \beta E_t\Delta p_{t+1} + \alpha y_t$

[13] In order to avoid possible semantic confusions, McCallum (1986) proposed that different terms be used for the two types of aberrational behavior, but this proposal has not met with widespread acceptance.

(13) $R_t = (1 + \mu_1) E_t\Delta p_{t+1} + \mu_2 y_t + e_t$.

Here we suppose that e_t in (13) is white noise, and that v_t in (11) is, as before, generated by a first-order autoregressive process with parameter ρ.

In this model the unique minimum-state-variable (MSV) rational expectations solution is of the form[15]

(14) $y_t = \phi_{11}v_t + \phi_{12}e_t$

(15) $\Delta p_t = \phi_{21}v_t + \phi_{22}e_t$.

Then we have $E_t y_{t+1} = \phi_{11}\rho_1 v_t$ and $E_t\Delta\rho_{t+1} = \phi_{21}\rho_1 v_t$; consequently, standard undetermined coefficient calculations yield

(16a) $\phi_{11} = 1/[1 - \rho_1 - b_1\mu_2 - (\alpha b_1\mu_1\rho_1)/(1 - \beta\rho_1)]$

(16b) $\phi_{12} = b_1/(1 - b_1\mu_2)$

(16c) $\phi_{21} = \alpha/[(1 - \beta\rho_1)(1 - \rho_1 - b_1\mu_2) - \alpha b_1\mu_1\rho_1]$

(16d) $\phi_{22} = \alpha b_1/(1 - b_1\mu_2)$.

Here there are unique values implied for $\phi_{11} > 0$, $\phi_{12} < 0$, $\phi_{21} > 0$, and $\phi_{22} < 0$, so the MSV solution suggests that there is no problem with the inflation-forecast targeting rule (13).

Suppose, however, that a researcher looks for non-MSV solutions of the form

(17) $y_t = \phi_{11}v_t + \phi_{12}e_t + \phi_{13}\Delta p_{t-1}$

(18) $\Delta p_t = \phi_{21}v_t + \phi_{22}e_t + \phi_{23}\Delta p_{t-1}$,

where the extraneous state variable Δp_{t-1} is included. These expressions imply $E_t y_{t+1} = \phi_{11}\rho_t v_t + \phi_{13}(\phi_{21}v_t + \phi_{22}e_t + \phi_{23}\Delta p_{t-1})$ and $E_t\Delta p_{t+1} = \phi_{21}\rho_1 v_t + \phi_{23}(\phi_{21}v_t + \phi_{22}e_t + \phi_{23}\Delta p_{t-1})$.

[14] Note that I am not disputing a different point, that central banks need to base policy on their own information and structural models, also discussed by Woodford (1994) and Bernanke and Woodford (1997).

Then undetermined coefficient reasoning implies that the values for the ϕ_{ij} are given by six relations analogous to (16) among which are

(19) $\phi_{13} = b_1\mu_1 \phi_{23}^2 + b_1\mu_2\phi_{13} + \phi_{13}\phi_{23}$

and

(20) $\phi_{23} = \beta\phi_{23}^2 + \alpha\phi_{13}$.

From these ϕ_{13} can be solved out, yielding the cubic equation

(21) $\phi_{23} = \beta\phi_{23}^2 + \alpha b_1\mu_1\phi_{23}^2/(1 - b_1\mu_2 - \phi_{23})$.

Inspection of the latter indicates that one solution is provided by $\phi_{23} = 0$, which implies $\phi_{13} = 0$. This, of course, gives the MSV solution obtained previously. But (21) is also satisfied by roots of the quadratic

(22) $\beta\phi_{23}^2 - [1 + \beta + \alpha b_1\mu_1 - b_1\mu_2\beta]\phi_{23} + (1 - b_1\mu_2) = 0$,

i.e., by

(23) $$\phi_{23} = \frac{d \pm [d^2 - 4\beta(1 - b_1\mu_2)]^{0.5}}{2\beta}$$

where d is the term in square brackets in (22). Therefore, for some values of the parameters α, β, b_1, μ_1, and μ_2 there may be other real solutions in addition to the MSV solution.

To keep matters relatively simple, let $\mu_2 = 0$ so that the policy rule responds only to expected inflation. Then d becomes $1 + \beta + \alpha b_1\mu_1$ and there will be two real roots to (22) if $\mu_1 < 0$ or $\mu_1 > \mu_1^c \equiv [2\beta^{0.5} + 1 + \beta]/(-b_1\alpha)$. Furthermore, while one of the ϕ_{23}

[15]The MSV concept is discussed at length in McCallum (1983, 1999), where it is interpreted as the unique solution that includes no bubble or sunspot components. A solution procedure is there proposed that generates a unique solution by construction in a very wide class of linear RE models.

values in (22) will exceed 1.0 in absolute value when $\mu_1 > \mu_1^c$, the other will not—it will be a (negative) stable root. Consequently, there will be no transversality condition to rule out that root's implied trajectory as a rational expectations equilibrium. Thus there is, for $\mu_1 > \mu_1^c$, an infinite multiplicity of stable RE solutions indexed by the initial start-up value of Δp_{t-1}. In such cases, moreover, "sunspot" solutions are also possible in the sense of not being ruled out by the conditions of RE equilibria.[16] This is the danger pointed out by the Woodford warning. Furthermore, it is made less likely when values of μ_2 exceed zero, thereby providing an additional reason to avoid pure inflation forecast targeting.[17]

I now wish to argue, as in Section 2, that the postulated danger may not be of any practical significance, for it is entirely possible that non-MSV—i.e., bubble and sunspot—solutions are empirically irrelevant.[18] That such is the case is a cogent and plausible hypothesis, which has not been convincingly contradicted by any empirical tests, despite the enormous amount of interest shown by researchers over the past 25 years.

The main line of argument, in favor of the proposition that only MSV solutions are of empirical relevance, again concerns the E-stability and learnability of the alternative solutions. For the model at hand, specifically, it is shown by Bullard and Mitra (2000, Figure 3) that the MSV solutions are E-stable, and therefore learnable by a real-time least-squares learning procedure, for the cases with large μ_1 and/or μ_2 values.[19]

[16] By a sunspot solution I mean one that includes random variables (of a martingale difference variety) that have no connection with other elements of the model.
[17] See, e.g., Bullard and Mitra (2000).
[18] At least, in macroeconomic contexts.
[19] As mentioned above, E-stability pertains to the convergence of meta-time iterations that may or may not drive non-RE expectations functions to their RE values, and it governs least-squares learnability.

Bullard and Mitra do not analyze the E-stability/learnability properties of the non-MSV solutions, but very closely related cases have been analyzed by Evans (1986, pp. 150-3) and Evans and Honkapohja (1999, pp. 487-506; 2000, Ch. 10). Their results indicate that the non-MSV solutions do not possess E-stability in the case at hand.

A second line of argument is developed in McCallum (2000b), from which this section is adapted. There it is emphasized (a) that the unique MSV solution is available in the high-μ_1 cases pointed to by the Woodford warning and (b) that this solution is well behaved in the sense of experiencing no discontinuity when μ_1 passes through the critical value that delineates the region of multiple stable solutions. Specifically, impulse response functions for the MSV solution are plotted and shown to be virtually indistinguishable for μ_1 values just above and just below the μ_1^c critical value at which solution multiplicity sets in. Also, the MSV impulse response functions change continuously with μ_1 more generally (McCallum, 2000b, Figs. 3-5). By contrast, the non-MSV solutions are not continuous at μ_1^c and also feature additional peculiarities. Those results illustrate, for the example considered, the well-behaved nature of the MSV solution and the erratic nature of the non-MSV (bubble) solutions. Such results also obtain for other parameter values and clearly suggest the desirability of considering the MSV solutions as the sole economically relevant solution.

If my suggested strategy is adopted, i.e., if the MSV solution is taken to represent implied behavior for the model at hand, then there is no compelling reason to believe that strong responses to forecast inflation values will generate undesirable behavior. In that case, preemptive inflation forecast targeting could be an attractive policy regime, despite warnings of the type under discussion.[20]

4. A Framework for Quantitative Open Economy Analysis

Whereas the points addressed in the previous two sections could be discussed in the context of extremely simple models with only qualitative specifications, such will not be true for the topics to be considered below. More realism will be needed in the specification of relations governing dynamics of both consumption and price adjustment behavior. In addition, it will be important to recognize the role of foreign trade of goods, services, and financial assets. Furthermore, a bit of additional realism will need to be applied in postulating alternative monetary policy rules. The present section, accordingly, will be devoted to a description of the open-economy model to be utilized in Sections 5-7 below.

The basic structure of the model follows that in McCallum and Nelson (1999), but with a few adjustments that are intended to improve its match with actual data. The M-N model was designed in the spirit of what has been called the "new open-economy macroeconomics."[21] In other words, it was intended to be a dynamic open-economy macro model that features rational expectations, optimizing agents, and slowly-adjusting prices of goods. It differs from other contributions in the area, however, in the manner in which imported goods are treated. In particular, the M-N model treats imports not as finished goods, as is usual, but instead as raw-material inputs to the home economy's production process. This alternative treatment leads to a cleaner and simpler theoretical

[20] This argument does not apply to the case with $\mu_1 < 0$, in which the "Taylor principle" does not hold and there is a genuine problem. For analysis and more discussion, see McCallum (2000b).
[21] For references to this line of work, see Lane (1999). Also see Brian Doyle's "New Open Economy Macroeconomics Homepage," http://www.geocities.com/brian_m_doyle/open.html.

structure, relative to the standard treatment, and is empirically attractive in ways that will be outlined below. Since the optimizing, general equilibrium analysis (from a small-economy perspective) has already been worked out in McCallum and Nelson (1999), here I will take an informal expository approach designed to facilitate understanding of the model's basic structure.

It is well known that optimizing analysis leads, in a wide variety of infinite-horizon models that involve imperfect competition, to a consumption Euler equation that can be expressed or approximated in the form

(24) $c_t = E_t c_{t+1} + b_0 + b_1 r_t + v_t$,

where c_t is the log of a Dixit-Stiglitz consumption-bundle aggregate of the many distinct goods that a typical household consumes in period t.[22] In (24), r_t is the real interest rate on home-country one period bonds (private or government) and v_t is a stochastic shock term that pertains to household preferences regarding present vs. future consumption. In closed economy analysis, relation (24) is often combined with a log-linearized, per-household, overall resource constraint to yield an "expectational IS function," to use the term of Kerr and King (1996). This step presumes that investment and capital are treated as exogenous. The simplest version of that assumption is that the capital stock is fixed; since that assumption is rather common in the new open-economy macro (NOEM) literature, we shall adopt it here.

For our open-economy application, one might be tempted to write the resource constraint as

(25) $y_t = \omega_1 c_t + \omega_2 g_t + \omega_3 x_t - \omega_4 im_t$

[22] Thus $c_t = \ln C_t$ with $C_t = [\int C_t(z)^{(\theta-1)/\theta} dz]^{\theta/(\theta-1)}$, where $\theta > 1$, z indexes distinct goods, and the integral is over (0,1), while the corresponding price index is $P_t = [\int P_t(z)^{1-\theta} dz]^{1/(1-\theta)}$.

where y_t, g_t, x_t, and im_t are logarithms of real output, government consumption, exports, and imports while ω_1, ω_2, ω_3, and ω_4 are steady-state ratios of consumption, government purchases, exports, and imports to output. But if imports are exclusively material inputs to the production of home-country goods, and $Y_t = \ln^{-1} y_t$ is interpreted as units of output, then the relevant identity is

(25′) $y_t = \omega_1 c_t + \omega_2 g_t + \omega_3 x_t$.

This is, of course, the same as (25) with $\omega_4 = 0$. Either of these versions can be thought of as the resource constraint for our model.

It is desirable that import demand be modelled in an optimizing fashion. Toward that end, assume that production of all consumer goods is effected by households that are constrained by a production function of the CES form, with labor and material imports being the two variable inputs. Then the cost minimizing demand for imports equals

(26) $im_t = y_t - \sigma q_t + \text{const.}$

where σ is the elasticity of substitution between materials and labor in production, and where "const." denotes <u>some</u> constant.[23] Also, q_t is the log price of imports in terms of consumption goods. In other words, $Q_t = \ln^{-1} q_t$ is the real exchange rate. Let P_t and S_t be the home country money price of goods and foreign exchange, with P_t* the foreign money price of home-country imports. Then if p_t, s_t, and p_t* are logs of these variables, we have

(27) $q_t = s_t - p_t + p_t^*$.

Symmetrically, we assume that export demand is given as

[23] That is, the expressions "const." in different equations appearing below will typically refer to different constant magnitudes.

(28) $x_t = y_t^* + \sigma^* q_t + \text{const.}$

where y_t^* denotes production abroad and σ^* is the price elasticity of demand from abroad for home-country goods.

Let us now consider output determination in a flexible-price version of the model. Taking a log-linear approximation to the home-country production function, we have

$$y_t = (1-\alpha)a_t + (1-\alpha)n_t + \alpha\, im_t + \text{const.},$$

where n_t and a_t are logs of labor input and a labor-augmenting technology shock term, respectively. We suppose for simplicity that labor supply is inelastic, with 1.0 units supplied per period by each household. Thus with price flexibility we would have $n_t = 0$ and the flexible-price, natural rate (or "potential") value of y_t will be

$$\bar{y}_t = (1\text{-}\alpha)\, a_t + \alpha\, [\bar{y}_t - \sigma q_t] + \text{const.},$$

or

(29) $\bar{y}_t = a_t - [\sigma\alpha/(1\text{-}\alpha)]\, q_t + \text{const.}$

But while $\bar{y}_t$ would be the economy's output in period t if prices could adjust promptly in response to any shock, we assume that prices adjust only sluggishly. And if the economy's demand quantity as determined by the rest of the system (y_t) differs from $\bar{y}_t$ then the former quantity prevails—and workers depart from their (inelastic) supply schedules so as to provide whatever quantity is needed to produce the demanded output, with im_t given by (26).

In such a setting, the precise way in which prices adjust has a direct impact on demand, in a manner to be detailed shortly, and consequently on production. There are various models of gradual price adjustment utilized in the recent literature that are intended to represent optimizing behavior. In our analysis below we shall explore two candidates; for present purposes we need to list at least one representative. Principally because it is the one used in previous work (McCallum and Nelson, 1999a), let us begin with the P-bar model, here expressed in the form

(30') $p_t - p_{t-1} = (1 - \phi_1)(\bar{p}_{t-1} - p_{t-1}) + E_{t-1}(\bar{p}_t - \bar{p}_{t-1})$.

Thus we specify that prices adjust in response to prior departures of p_t from its market-clearing value ($\bar{p}_t$) and to expected changes in the latter. In our tabulation of endogenous variables, however, neither p_t nor $\bar{p}_t$ needs to be included in addition to Δp_t. The reason is that (30') is logically equivalent to $E_{t-1}(p_t - \bar{p}_t) = \phi_1(p_{t-1} - \bar{p}_{t-1})$ and thus to

(30) $E_{t-1}(y_t - \bar{y}_t) = \phi_1(y_{t-1} - \bar{y}_{t-1})$,

as is shown in McCallum and Nelson (1999). The same conclusion regarding endogenous variables holds, moreover, if we turn to the second model of price adjustment to be considered below. The adjustment relation in that case is

(30'') $\Delta p_t = 0.5(E_t\Delta p_{t+1} + \Delta p_{t-1}) + \phi_2 (y_t - \bar{y}_t) + u_t$,

where u_t is a behavioral disturbance. This form of equation has been fairly prominent in recent work,[24] primarily because it tends to impart a more realistic degree of persistence to inflation than does the (more theoretically attractive) Calvo-Rotemberg model.

A standard feature of most current open-economy models is a relation implying uncovered interest parity (UIP). Despite its prominent empirical weaknesses, accordingly, we adopt one here:

(31) $R_t - R_t^* = E_t\Delta s_{t+1} + \xi_t$.

We include a time-varying "risk premium" term ξ_t, however, that may have a sizeable variance and could be autocorrelated.

It remains to describe how monetary policy is conducted. In the spirit of most recent research in monetary economics, we presume that the monetary authority conducts policy in a manner suggested by the Taylor (1993a) rule, i.e., by adjusting a one-period nominal interest rate in response to prevailing (or forecasted future) values of inflation and the output gap, $\tilde{y}_t = y_t - \bar{y}_t$:

(32) $R_t = (1-\mu_3)\,[\mu_0 + \Delta p_t + \mu_1(\Delta p_t - \pi^*) + \mu_2 \tilde{y}_t] + \mu_3 R_{t-1} + e_t.$

Our quantitative results below will be based on estimated or calibrated versions of this rule, in most cases with E_{t-1} applied to $\tilde{y}_t$ and Δp_t.

To complete the model, we need only to include the Fisher identity, $(1 + r_t) = (1 + R_t) / (1 + E_t\Delta p_{t+1})$, which we approximate in the familiar fashion:

(33) $r_t = R_t - E_t\Delta p_{t+1}.$

Thus we have a simple log-linear system in which the ten structural relations (24)-(33) determine values for the endogenous variables y_t, $\bar{y}_t$, Δp_t, r_t, R_t, q_t, s_t, c_t, x_t, and im_t. Government spending g_t and the foreign variables p_t^*, y_t^*, R_t^* are taken as exogenous—as are the shock processes for v_t, a_t, e_t, and ξ_t. I would suggest that this is probably the simplest and cleanest model extant that includes the essential NOEM features.

Of course, it would be possible to append a money demand function such as

(34) $m_t - p_t = \gamma_0 + \gamma_1 y_t + \gamma_2 R_t + \eta_t,$

and one of this general form—perhaps with c_t replacing y_t—would be consistent with optimizing behavior.[25] But, as many writers have noted, that equation would serve only to determine the values of m_t that are needed to implement the R_t policy rule.

[24] See Fuhrer and Moore (1995) and Clarida, Gali, and Gertler (1999).
[25] See McCallum and Nelson (1999) or Woodford (1995, 2000).

With the structure given above, it is possible to calculate the (log of the) balance on goods and services account—i.e., net exports—as

(35) $net_t = x_t - (im_t + q_t)$,

where it is assumed that $\omega_3 = \omega_4$. Also, we can calculate the log of the GDP deflator as

(36) $p_t^{DEF} = [p_t - \omega_3(s_t + p_t^*)]/(1 - \omega_3)$.

These represent extra features, however, that need not be included with the basic model (24)-(33).

Before moving on, it should be noted that an advantage of our strategy of modeling imports as material inputs to the production process is that the relevant price index for produced goods is the same as the consumer price index, which implies that the same gradual price adjustment behavior is relevant for all domestic consumption. In addition, it avoids the unattractive assumption, implied by the tradeable vs. non-tradeable goods dichotomization, that export and import goods are perfectly substitutable in production.

Theoretical advantages would not constitute a satisfactory justification, of course, if it were the case that in fact most imports are consumption goods. Such is not the case, however, at least for the United States. Instead, an examination of the data suggests that (under conservative assumptions) productive inputs actually comprise a larger fraction of U.S. imports than do consumer goods (including services).[26]

[26] For the year 1998, imported consumer goods amounted to \$453 billion while imports of business inputs came to \$624 billion, approximately. These figures are based on an examination of categories reported in the August 1999 issue of the Survey of Current Business. For several categories it is clear whether they are composed predominantly of consumer or business goods. For others, judgemental assignments were required. Those assignments are as follows, with the reported figure being the fraction of the category

5. Calibration and Model Properties

There is one way in which the model developed in McCallum and Nelson (1999) differs significantly from the 10-equation formulation just presented. Specifically, our M-N model includes a somewhat more complex form of consumption vs. saving behavior, one that features habit formation. Thus in place of the time-separable utility function that leads to equation (24), we assume that each period-t utility term includes $c_t/(c_{t-1})^h$, with $0 \leq h < 1$, rather than c_t alone. This specification gives rise to the following replacement for (24):

(24') $\quad c_t = h_0 + h_1 c_{t-1} + h_2 E_t c_{t+1} + h_3 E_t c_{t+2} + h_4(\log \lambda_t) + v_t.$

Here λ_t is the Lagrange multiplier on the household's budget constraint, which obeys

(37) $\quad \log \lambda_t = \text{const.} + E_t\lambda_{t+1} + r_t,$

and there are constraints relating the h_j parameters to others in the system. For details and additional discussion, see M-N (1999) and the recent study of Fuhrer (2000).

Calibration of the model draws on M-N (1999) but differs in a few ways that, in retrospect, seem appropriate. For the parameters governing spending behavior, I retain here the h = 0.8 value taken from an early version of Fuhrer (2000), but for the counterpart of b_1 I now use 0.4, rather than 1/6, in order to reflect the greater responsiveness of investment spending, which is not included explicitly in the model.[27] For σ, the elasticity of substitution in production (and therefore the elasticity of import demand with respect to Q_t), I again use 1/3, and for the elasticity of export demand with respect to Q_t the same value is used. In (29), the labor-share parameter $1-\alpha$ equals 0.64.

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classified as "business inputs:" Automotive vehicles, engines, and parts, 25%; Travel, 25%; Passenger fares, 25%; Foods, feed, and beverages, 50%; and Other private services, 75%.

[27] The parameter in question is the intertemporal elasticity of substitution in consumption when h = 0.

The steady state ratio of imports (and exports) to domestic production is taken to be 0.25, a higher value than in M-N (1999) so as to reflect an economy more open than is the United States. Unlike M-N (1999), I include government consumption, setting $\omega_2 = 0.25$.

In the two price adjustment specifications, the parameter values are $\phi_1 = 0.89$ (estimated by M-N) and $\phi_2 = 0.02$. The latter value is based on my reading of a wide variety of studies, plus conversion into non-annualized fractional terms for a quarterly model. Policy rule parameters are varied in our experiments, but should be thought of in relation to realistic values close to $\mu_1 = 0.5$, $\mu_2 = 0.4$, and $\mu_3 = 0.8$, the latter reflecting considerable interest rate smoothing.[28] In most cases, expectations based on t-1 data will be used for the Δp_t and $\tilde{y}_t$ variables appearing in the policy rule, in order to make our version of the rule operational.

The stochastic processes driving the model's shocks must also be calibrated, of course. For both foreign output and the technology shock, I have specified AR(1) processes with AR parameters of 0.95, rather than the 1.0 values used in M-N (1999). The innovation standard deviations (SD) are 0.03 and (as before) 0.0035. The latter value might appear smaller than is usual, but is appropriate to generate a realistic degree of variability in $\bar{y}_t$ when the latter is not exogenous but is dependent on q_t. The UIP risk premium term ξ_t is generated by an AR(1) process with AR parameter 0.5 and innovation 0.04; these values are based on work reported in Taylor (1993b). Government consumption (ln logs) follows an AR(1) process, with AR parameter 0.99 and innovation

[28] The coefficient attached to the output gap actually equals 0.1 in the simulations, as they include results based on per-quarter fractional units. But for comparison with the literature on Taylor rules, which works with annualized percentages, I will here describe the number as 0.4.

SD of 0.02. Finally, the v_t, u_t and e_t shock processes are taken to be white noise with SD values of 0.011, 0.002 and 0.0017, respectively.

One way to represent a model's properties is in terms of its variances and autocovariances. Unconditional variances for some of the model's crucial variables are shown in Table 1 for various specifications. The first four columns pertain to the variant with the P-bar price adjustment equation (30'), whereas the last four columns are based on the alternative adjustment relation (30''). Two assumptions are considered for the share of exports to total production, namely, that this share is 0.10 or 0.25. The former represents a large economy that is relatively closed to foreign trade whereas the latter figure is for a more typical economy. Finally, policy rule (32) is used both with and without interest smoothing, i.e., with $\mu_3 = 0.8$ (the more realistic case) and with $\mu_3 = 0$ (as in the original version of Taylor's rule). In both cases the other coefficients are given the values mentioned above.

It is clear from Table 1 that the P-bar variant of the model generates more variability in all principal variables than does the equation (30'') variant. There is no specific economy whose moments we are trying to match, but knowledge of values for the United States gives one the impression that that the variant (30'') values are—though slightly too small—the more realistic of the two sets. It is also clear that our model generates much more variability when the economy is more open to foreign trade. This is not surprising, since more trade leads to a bigger effect of exchange rate movements on the natural-rate value of output. For the purposes of the present paper, we will in what follows be most concerned with the more open of the two specification, i.e., the one with an export (or import) to output ratio of 0.25. Finally, the table also indicates that in most cases interest rate smoothing (i.e., $\mu_3 = 0.8$) helps to reduce the variability of inflation and the output gap.

Another way to represent the model's properties is in terms of its impulse response functions. The responses to a unit shock to the policy rule (i.e., a 1.0 realization of the shock e_t) are shown in Figure 3 for $\mu_3 = 0.8$. There it will be seen that this temporary tightening of monetary policy induces temporary but lasting drops in output, inflation, and both the real and nominal exchange rate, together with a temporary increase in net exports. The dynamic patterns are somewhat different for the two price adjustment specifications, with much more inflation persistence apparent in the second case. Since this persistence is more consistent with observed behavior of inflation in most developed economies, this difference in outcomes favors the specification (30''). Consequently, this specification will be emphasized in what follows and will henceforth be referred to as our "standard" price adjustment specification. A questionable feature of both models is that the exchange rates and net exports respond promptly to shocks, rather than with a lagged and/or gradual pattern. Overall, however, the nature of the models' responses are encouraging. The magnitude of the output response to a policy shock is somewhat larger than in M-N (1999), but this is due to the larger share of foreign trade.

6. Frequency of ZLB Occurrences with Inflation Targeting

We now begin our examination of the effects of inflation targeting, as compared with other monetary policy regimes, on the frequency of liquidity-trap problems. The general strategy is to conduct simulations and determine how often a liquidity-trap or ZLB (zero lower bound) constraint is encountered with various policy rules, including inflation targeting. For a given model, the frequency of ZLB constraints being encountered will of course depend upon R*, the sum of the target inflation rate π^* and the average real rate of interest r. The smaller is π^*, the more frequently will the constraint be encountered but it is possible that this frequency could be quite low even with a reasonably small value of π^*, say, 2.0 percent per year (i.e., 0.005 in quarterly fractional terms).

Before beginning, one technical matter needs to be discussed. In the simulations to be reported, no ZLB constraint will actually be imposed. Instead, in order to maintain a linear computational framework, the simulations will permit negative rates of interest. Therefore, the number of periods with such rates would be an overestimate of how frequently ZLB constraints would be binding, since in some periods the previous period's rate will have been negative. In order, then, to get an estimate of how often ZLB constraints would be encountered, I will examine the frequency of periods (quarters) in which the recorded interest rate is negative <u>and</u> lower than in the previous period. (If a value is negative but higher than in the previous period, the presumption is that R_t movement would also be upward in the model with a ZLB constraint, so the bound would not be encountered.) To illustrate, Table 2 reports relative frequencies of three statistics pertaining to the ZLB. The first is the fraction of periods in which negative rates are realized.[29] The second is our preferred measure, the fraction of periods in which negative rates are realized and the realized value is lower than in the previous period. The third is the fraction of periods in which negative rates are realized and the value in the previous period was positive. This latter statistic is designed to indicate how many episodes of zero or negative rates occur, with each string of zero or negative values counted only once.

Several assumptions regarding R* are investigated in Table 2, i.e., values ranging from 2 to 8 percent per year (0.005 to 0.02 in quarterly fractional units). If one believed that an economy's average real rate of interest was about 3 percent and its inflation target was set at 2 percent, then the relevant figure for R* would be 5 percent. For the calculations in Table 2, the standard version of the model is utilized and the policy rule parameters μ_1, μ_2, and μ_3 are set at 0.5, 0.4, and 0.8, respectively. It will be seen that with R* = 5 percent, negative interest rates are encountered in 1.58 percent of the quarterly time periods. But our preferred measure, for the reasons just explained, is given by the second statistic, which equals 1.08 percent of the time periods. Finally, the third statistic takes on a still smaller value, of 0.61 percent, for the relative frequency of episodes in which interest rate constraints are encountered. Of course the frequencies are all higher for lower values of R*, with (e.g.) the ZLB constraint binding quite rarely at R* = 7.0 but with a disturbingly high frequency for an R* of 2.0 or 3.0. But the main point here is that the regular and intuitive behavior of the three different statistics gives confidence that the second statistic is indeed providing a reasonable measure of the frequency of periods in which the ZLB would be encountered if we were to use nonlinear methods. In what follows, consequently, only that statistic will be reported, and will be described simply as the fraction or percentage of periods in which the ZLB constraint is binding. (Also, see footnote 31 below.)

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[29] Actually, the simulations are carried out with all constant terms set equal to zero. Thus the observations described as negative are those in which the simulated value is less than –R*. This way of proceeding is entirely innocuous.

We now turn to our first set of basic substantive results, which are premised on the assumption that a value of 5 percent per year is appropriate for R*. As mentioned above, 100 simulations are run for each case and their average results are reported in Table 3. The object is to consider alternative values for the policy rule parameters μ_1, μ_2, and μ_3 to determine the relative desirability of different rules. In each cell of Table 3, the three numbers represent the standard deviation of inflation, the standard deviation of the output gap, and the frequency of times that the ZLB occurs. All of these are reported in percentage (not fractional) units, with the inflation figure annualized. The inflation and output gap figures should be interpreted as root-mean-square deviations from their target values.

In Table 3, a wide range of values is considered for μ_1, the strength of reaction to the inflation variable: values from 0.1 to 10. Also, the degree of interest rate smoothing, measured by μ_3, is varied over a wide range from 0 to 0.99. Only two values are reported, however, for μ_2, the response coefficient on the output gap. First, a value of 0.4 is considered as it is close to the original Taylor-rule value of 0.5. Larger magnitudes are not explored because I believe that it is very dangerous to respond strongly to perceptions of the output gap because of the difficulty of measuring or even conceptualizing an operational measure of "potential" output.[30] Second, with a value of μ_2 equal to zero, we have a rule that might be considered representative of pure inflation targeting.

Looking at Table 3 it can be seen that ZLB cases appear with excessive frequency for all cases with no interest smoothing or only a small degree (i.e., $\mu_3 = 0.5$). At the value 0.8, which is close to those estimated empirically by Clarida, Gali, and Gertler

[30] For some discussion and results pertaining to this danger, see McCallum and Nelson (2000).

(1997, 1999) and McCallum and Nelson (1999), most of the cases still show ZLB problems arising in over 1 percent of the quarterly time periods. With $\mu_3 = 0.9$, however, the frequency of ZLB periods becomes acceptably small.[31] Next, larger values of the inflation coefficient μ_1 lead invariably to reduced variability of inflation about its target value. Increasing μ_1 from 0.1 to 1.0, moreover, tends to reduce the variability of the output gap and the frequency of ZLB occurrences. Higher values, however, seem not to be helpful on balance. Finally, a comparison of the bottom and top halves of the table indicate that there is little to choose between the pure inflation targeting case with $\mu_2 = 0$ and the case with moderate, Taylor-style responses to the output gap (i.e., with $\mu_2 = 0.4$).

Next we turn to other, non-Taylor-style, rules that utilize target variables other than inflation. From the perspective of actual practice, the most important are ones that utilize the exchange rate, or its rate of change, as the principal target variable. Thus we consider policy rules of the form

(38) $R_t = (1-\mu_3)\,[\mu_0 + \Delta p_t + \mu_1\,(z_t - z^*)] + \mu_3\,R_{t-1} + e_t,$

where z_t is the target variable. Letting s_t denote the log of the home-country price of foreign exchange, we will experiment with s_t and Δs_t as examples of z_t. In addition, since several analysts have promoted nominal income, or its growth rate, as a target variable, we shall also use $x_t = y_t + p_t$ and Δx_t for z_t. As before, we actually use $E_{t-1}\Delta p_t$ rather than Δp_t in (38) and also use the t−1 expectation of x_t and Δx_t. For the exchange rate,

[31] It might be asked how these results compare with those of Reifschneider and Williams (2000), who use the FRB/US econometric model and actually impose a proper ZLB. In their Table 1, they report results for a case with a Taylor rule with coefficients $\mu_1 = 0.5$, $\mu_2 = 0.5$, and $\mu_3 = 0$. They assume r = 2.5 percent per year, so their case with an inflation target of 2 percent implies a R* value of 4.5 percent, which leads to a frequency of ZLB periods of 5 percent. When I use these settings, I get 8 percent which is close and on the conservative side.

however, it is assumed that the current-period value is observable and so appears in the rule. In addition, we want to consider price level targeting, i.e., the use of $E_{t-1}p_t$ rather than $E_{t-1}\Delta p_t$ as the rule's target variable. This choice does not necessarily imply that the target for the price level is constant over time, but if it grows at a constant rate then target misses for the price level will have to be reversed subsequently.

Results are shown in Table 4. In all cases considerable interest smoothing is assumed, with a realistic value of 0.8 for μ_3. In the first column, we repeat figures from Table 3 for the sake of reference. Then the second and third columns give results for s_t and Δs_t. With $\mu_1 = 0.1$, the performance of the s_t target is rather good, about as good as for Δp_t with $\mu_1 = 0.5$, but in all other cases both of the exchange rate targets give quite poor results with very high frequencies of ZLB occurrences. Evidently the high degree of variability of the exchange rate leads to a great deal of interest variability and thus to a high frequency of ZLB constraints. The nominal income level target performs rather well for values of μ_1 up to 1.0, but induces many ZLB periods when $\mu_1 = 10$. The nominal income growth target performs less well, although its performance is not too bad for $\mu_1 =$ 0.5 or 1.0. Finally, the price level target yields very good results when μ_1 equals 0.1 or 0.5, but induces a high frequency of ZLB constraints with stronger feedback parameters.

With regard to the basic policy issue at hand, our conclusions are as follows. In comparison with other growth rate targets (Δs_t and Δx_t), inflation targeting performs somewhat better in other respects and about the same with regard to the ZLB problem. In comparison to a price level target, the performance of inflation targeting appears to be less good for stabilizing inflation and output, but less open to serious ZLB problems. Exchange rate level targeting is most sensitive to the ZLB problem of any of the targets considered. Finally, nominal income level targeting seems to perform quite well, but not so well as to dominate inflation targeting.

7. Monetary Stabilization Despite a Liquidity Trap Situation

Now we alter our perspective to argue that, even if an economy has its interest rate instrument immobilized because of a liquidity trap or ZLB situation, there is nevertheless scope for monetary stabilization policy provided that the economy is open—as all are—to foreign trade. The argument follows that presented in McCallum (2000a) but with a model that is improved and more open, as described above.[32] Specifically, let us suppose that our model economy has its interest rate fixed rigidly at $R_t = 0$ (or some other constant value), but that the monetary authority adopts a policy rule with an exchange rate <u>instrument</u>—not target—of the following specification:

$$s_t - s_{t-1} = \nu_0 - \nu_1(E_{t-1}\Delta p_t - \pi^*) - \nu_2 E_{t-1}(y_t - \bar{y}_t) + \zeta_t \qquad \nu_1 > 0\ ;\ \nu_2 \geq 0. \tag{39}$$

Here the rate of depreciation of the foreign exchange rate is lowered if inflation and/or output exceeds its target value. The exchange rate is being used as an instrument or indicator variable in much the same way as is normally the case (in advanced economies) with a short-term interest rate. Thus the central bank uses open-market operations or standing facilities to keep the asset price at the value desired—the value specified by the policy rule—so as to promote the achievement of macroeconomic targets (inflation and output).

To represent such a policy process, (39) is included in our model in place of (32). Then, since R_t is no longer a variable, one of the model's equations must be deleted or else modified so as to introduce another endogenous variable. For the moment let us think of this step as involving the deletion of uncovered interest parity, as expressed in equation (31). This is only a shorthand method of describing the actual alteration involved, however, which will be explained and defended below. Our purpose now is to demonstrate that with policy rule (39) in place, stabilizing monetary policy can be conducted even though the nominal interest rate is held fixed at a constant value.

The main simulation results[33] are given in Table 5. There it can readily be seen that as ν_1, the coefficient attached to the inflation target, is increased the variability of inflation drops sharply—i.e., inflation is stabilized. Also larger values of ν_2, the coefficient on the output gap target, lead to reduced variability of the output gap.

Another way of demonstrating the effectiveness of monetary policy stabilization with the policy rule (39) is via impulse response functions. In Figure 4, the top panels present the responses of key endogenous variables to a policy rule shock, i.e., an upward blip in Δs_t, when the rule parameter values are $\nu_1 = 1.0$ and $\nu_2 = 1.0$. This loosening of policy brings about an increase in both inflation and output, as would be expected. Then in the bottom panels the rule parameter ν_2 is set at the larger value of 10. Thus the rule is designed to exert stronger stabilizing tendencies for inflation. And indeed the response of inflation (and output) to the shock are muted in comparison to the top panels. Next, a similar comparison is provided in Figure 5 for the case of a technology shock, which tends to increase output and decrease inflation. Again the bottom panels feature the higher value for ν_2 and again the inflation and output responses are muted by this

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[32] I do not intend to suggest that this proposal represents the only way of combating ZLB problems. Other possibilities are promoted by Goodfriend (2000) and Meltzer (1999). For Svensson (2000), see below.

[33] The disturbance ζ_t is assumed to possess the same stochastic properties as ξ_t in (31).

stronger attempt at stabilization. The cost, of course, is that the nominal and real exchange rates both respond more strongly, since the former is the policy instrument variable. These responses induce larger fluctuations in net exports, as well. From the results shown in Table 4 and Figures 4 and 5, it seems clear that the policy rule (39) does exert stabilizing influence on the economy despite the liquidity-trap immobilization of the nominal interest rate.

Let us now take up some issues regarding our way of modelling this phenomenon. In his comment on McCallum (2000a), Christiano (2000) has objected to the elimination of the uncovered interest parity (UIP) relationship from the model.[34] That this objection would be made is surprising, given the enormous volume of empirical evidence that finds major departures from UIP. Indeed, in the most standard empirical test, the slope coefficient that should equal 1.0, if UIP holds, usually turns out to be negative—often significantly so.[35] Thus it seems peculiar to insist on inclusion of the relation, since its drastic empirical failure is well documented. Despite this evidence, UIP is retained in many models, of course, but that is partly because it is unclear how to complete the model in its absence.[36] But that is no problem if the exchange rate is used as the instrument variable; the relation can simply be omitted. This strategy is entirely analogous to the omission of a base money demand function from models in which an interest rate is used as the instrument. The point is that in such cases it is not necessary to know how much base money must be supplied to set R_t at its desired value since its current value is immediately observable in the asset markets. Thus a poor understanding

[34] Indeed, Christiano's lengthy comment consists largely of variously-expressed assertions to the effect that a model should include the UIP relation.
[35] Well-known references include Lewis (1990) and Froot and Thayler (1990).

of the demand function for base money does not preclude the use of an interest rate instrument in standard models because the only role of the base money demand function is to specify how much base money must be supplied to implement the interest rate rule. In the case of the exchange rate instrument it again is not necessary to know the magnitude of the exchange market purchases (increases in base money) needed to implement the rule, because the value of the exchange rate can be immediately observed from the relevant asset market (the foreign exchange market).

In McCallum (2000a), it is recognized that the foregoing argument implies that there is some effect on the home country's exchange rate of purchases of foreign exchange with domestic base money. In other words, it is assumed that domestic and foreign currency assets are not perfect substitutes. In that paper the lack of perfect substitutability was described in terms of the "portfolio balance" model of exchange rate determination that has been out of favor since the late 1970s.[37] That particular description is not necessary; it was adopted primarily in the belief that it would make the general argument more transparent. The fundamental point is merely that assets denominated in home- and foreign-country currencies are not perfect substitutes so there is scope for departure from exact UIP to be affected by unsterilized purchases of foreign exchange, possibly in very large quantities.[38]

Svensson (2000) has put forth a proposal that, although different in detail, is in essence closely related to the use of a policy rule such as (39). Svensson's "foolproof"

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[36] For many purposes, use of the UIP assumption is in my opinion entirely sensible. The application under discussion here is, however, an extreme special case.
[37] Recently, however, specialists in exchange rate analysis have shown a renewed attraction to the basic aspects of this approach; see Flood and Marion (2000) and Jeanne and Rose (1999).
[38] Notable recent evidence that dollar and Deutschemark assets are not perfect substitutes, based on market-microstructure analysis, is provided by Evans and Lyons (2000).

way of providing monetary stimulus, when a country cannot reduce R_t because of a ZLB, is to (i) announce an upward sloping p_t path with the initial value above the current price level; (ii) announce that the currency will be devalued immediately and will depreciate henceforth at the rate of increase planned for the price level; (iii) announce that the scheme will be converted into a normal price-level or inflation targeting arrangement once the target price path has been achieved, and (iv) implement (ii) by offering to buy and sell foreign exchange at the specified value. The first, second, and fourth parts of this scheme are clearly much like the adoption of an inflation target and use of exchange rate depreciation as implied by (39). Svensson understandably emphasizes the differences between his scheme and the one presented in McCallum (2000a). But he exaggerates the differences, I believe, in stating that his argument "does not depend on any portfolio-balance effect of foreign-exchange interventions, in contrast to the argument of Meltzer [(1999)] and McCallum [(2000a)], and thus, it is more general…. As long as the central bank supplies an unlimited amount of domestic currency at the target exchange rate…, arbitrage in the foreign-exchange market will ensure that this exchange rate is the equilibrium exchange rate" (Svensson, 2000, p.24). My point is that exactly the same can be said for (39); the central bank is by assumption willing to make whatever unsterilized exchange market purchases (or sales) are needed to make s_t take on the value that the rule specifies. That Svensson's path for s_t is not contingent upon other variables does not alter this aspect of the situation. Or, to put the matter differently, if domestic and foreign assets were perfect substitutes, which they are not, then the central bank of the economy in question would not be able to achieve the initial exchange rate specified by his scheme.[39]

[39] Both his scheme and mine, incidentally, are viable only under the provisio that the situation is one in

8. Conclusion

Let us now conclude with a brief summary of the paper's contents. First, it is argued that the danger of a liquidity trap induced solely by self-confirming expectations, due to the existence of two rational expectations equilibria when there is a zero floor on interest rates, is probably minimal. Such a situation implies that the trap equilibrium, which is of a bubble nature, prevails despite the existence of a well-behaved MSV or fundamental equilibrium that yields the target rate of inflation. Crucially, it is indicated that the MSV solution possesses the property of E-stability, which implies that it is achievable by an adaptive least-squares learning process, while the trap equilibrium is not. The paper's suggestion is that this form of a liquidity trap represents a theoretical curiosity that is not of practical importance.[40]

Second, a similar analysis applies to the issue of "indeterminacy" induced by a policy rule that responds strongly to expected future inflation, rather than to currently observed or recent inflation. This situation again appears to be more of a theoretical curiosity than a genuine problem. In considering this issue, it is important to be clear about the nature of two very different concepts of "indeterminacy" that have been prominent at different times in the monetary policy literature.

Third, the likelihood of encountering a liquidity trap or ZLB situation, in which the central bank is powerless to combat a recession by reduction of short-term nominal interest rates, is studied quantitatively. This exercise requires a carefully calibrated

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which a liquidity trap needs to be escaped by raising the inflation rate and depreciating the currency. In this case the central bank will not run out of reserves, because it is supplying domestic currency that it can print in unlimited amounts. A major reason why it is widely believed that central banks have no control over exchange rates is that in practice most attempts have been to keep the value of the domestic currency higher than the equilibrium rate, not to lower it to a non-ZLB rate. In the former case the need is to supply large amounts of foreign exchange (which cannot be printed by the economy in question).

numerical model of an open economy; the one used here is adapted from McCallum and Nelson (1999). The paper's findings are that the chances of ZLB constraint are strongly dependent upon the sum of the inflation target and the long-run average real rate of interest. If that sum is five percent per year, the chances of encountering the ZLB constraint can be kept well below one percent per quarter-year by an interest rate policy rule that targets inflation and incorporates a fairly high degree of interest rate smoothing. The difficulty of avoiding the ZLB problem is not exacerbated by adoption of the inflation rate, rather than other candidate macroeconomic measures, as the target variable.

Finally, a policy rule for escaping a ZLB situation, if the economy does fall into a liquidity trap, is described and its properties explored. The proposed rule is one that (temporarily) makes the foreign exchange rate the instrument variable, rather than the immobilized interest rate. Macroeconomic stimulus is generated by the purchase (with base money) of foreign exchange so as to satisfy the rule, which includes inflation as a principal target variable. Simulation exercises and impulse response functions indicate that macroeconomic stabilization can in fact be exerted by monetary policy in this manner, despite ZLB immobilization of the usual interest rate instrument.

[40] The recent experience of Japan is quite different; it represents a situation in which the target inflation rate is too low so that the economy can fall into a trap of the fundamental type, as in the examples of Section 6.

Table 1

Standard Deviations of Δp_t, y_t, $\tilde{y}_t$, R_t

P bar variant	P bar variant	P bar variant	P bar variant	Eq.(30'') variant	Eq.(30'') variant	Eq.(30'') variant	Eq.(30'') variant
0.1 trade share	0.1 trade share	.25 trade share	.25 trade share	0.1 trade share	0.1 trade share	.25 trade share	.25 trade share
$\mu_3 = 0.0$	$\mu_3 = 0.8$	$\mu_3 = 0.0$	$\mu_3 = 0.8$	$\mu_3 = 0.0$	$\mu_3 = 0.8$	$\mu_3 = 0.0$	$\mu_3 = 0.8$
4.41	4.42	10.20	7.94	2.38	2.18	2.58	2.39
2.22	1.98	4.41	3.91	1.19	1.19	1.46	1.59
2.56	2.25	6.31	4.81	1.02	1.02	1.91	2.11
5.78	2.80	13.12	5.48	2.97	2.97	3.40	2.22

Table 2

Relative Frequencies of ZLB Statistics

R*, percent p.a.	Statistic 1	Statistic 2	Statistic 3
8.0	0.0001	0.0001	0.0001
7.0	0.0006	0.0004	0.0003
6.0	0.0088	0.0060	0.0034
5.0	0.0158	0.0108	0.0061
4.0	0.0408	0.0269	0.0126
3.0	0.0882	0.0565	0.0243
2.0	0.1990	0.1232	0.0423

Table 3

Performance Measures with Standard Model and R* = 5.0 Percent

Std. dev. of inflation, std. dev. of output gap, and percent of ZLB periods

μ_1, μ_2	$\mu_3 = 0.0$	$\mu_3 = 0.5$	$\mu_3 = 0.8$	$\mu_3 = 0.9$	$\mu_3 = 0.99$
0.1, 0.4	4.91 2.04 12.18	4.10 2.13 9.03	3.32 2.31 3.36	3.23 2.49 0.71	20.18 10.88 0.00
0.5, 0.4	2.63 1.94 5.93	2.52 1.98 4.07	2.36 2.11 1.23	2.60 2.31 0.34	17.33 8.40 0.00
1.0, 0.4	2.16 1.91 6.39	2.07 1.93 3.30	2.06 2.04 0.81	2.26 2.19 0.15	11.79 6.65 0.00
10.0, 0.4	1.28 2.09 20.31	1.29 2.09 13.80	1.36 2.07 6.66	1.50 2.09 2.96	2.95 2.55 0.03
0.1, 0.0	4.85 2.12 11.64	4.11 2.17 8.32	3.25 2.35 3.49	3.29 2.59 0.57	22.31 12.03 0.00
0.5, 0.0	2.60 1.98 6.34	2.42 2.06 3.32	2.32 2.16 0.61	2.55 2.35 0.18	16.59 9.05 0.00
1.0, 0.0	2.15 1.95 5.89	2.03 2.00 3.17	2.05 2.12 0.92	2.22 2.24 0.16	12.36 6.98 0.01
10.0, 0.0	1.29 2.14 19.60	1.26 2.13 13.37	1.35 2.12 7.30	1.50 2.09 2.88	3.01 2.56 0.01

Table 4

Performance Measures with Alternative Targets and R* = 5 Percent

Std. dev. of inflation, std. dev. of output gap, and percent of ZLB periods with policy rule (38) and $\mu_1 = 0.8$

μ_1	$E_{t-1}\Delta p_t$	s_t	Δs_t	$E_{t-1}x_t$	$E_{t-1}\Delta x_t$	$E_{t-1}p_t$
0.1	3.25	2.51	3.25	1.98	3.39	1.97
	2.35	2.05	2.40	2.16	2.44	2.18
	3.49	0.56	3.25	0.02	3.67	0.03
0.5	2.32	2.66	2.58	1.79	2.47	1.63
	2.16	1.91	2.34	2.12	2.34	2.21
	0.61	8.60	7.37	0.10	0.72	0.50
1.0	2.05	2.79	2.73	1.70	2.26	1.50
	2.12	1.90	2.26	2.12	2.40	2.29
	0.92	13.99	16.57	0.27	0.63	1.81
10.0	1.35	2.93	2.81	1.60	2.44	1.09
	2.12	2.01	1.81	2.04	3.10	2.87
	7.30	24.60	26.60	5.89	2.72	15.21

Table 5

Performance Measures with Policy Rule (39) and Fixed R

Standard Deviations of Δp_t, $\tilde{y}_t$, and Δs_t

ν_1	$\nu_2 = 0$	$\nu_2 = 1$	$\nu_2 = 10$	$\nu_2 = 50$
0	11.66 5.73 18.61	8.86 4.56 17.22	4.00 2.14 18.47	4.12 1.52 26.24
1	6.46 3.91 17.74	5.54 3.49 17.46	3.27 2.02 18.49	3.55 1.49 25.32
10	2.14 2.52 21.23	2.05 2.40 20.66	1.93 1.88 20.84	2.51 1.47 24.34
50	1.23 2.63 33.35	1.23 2.57 32.78	1.30 2.21 30.11	1.64 1.68 27.43

Figure 1

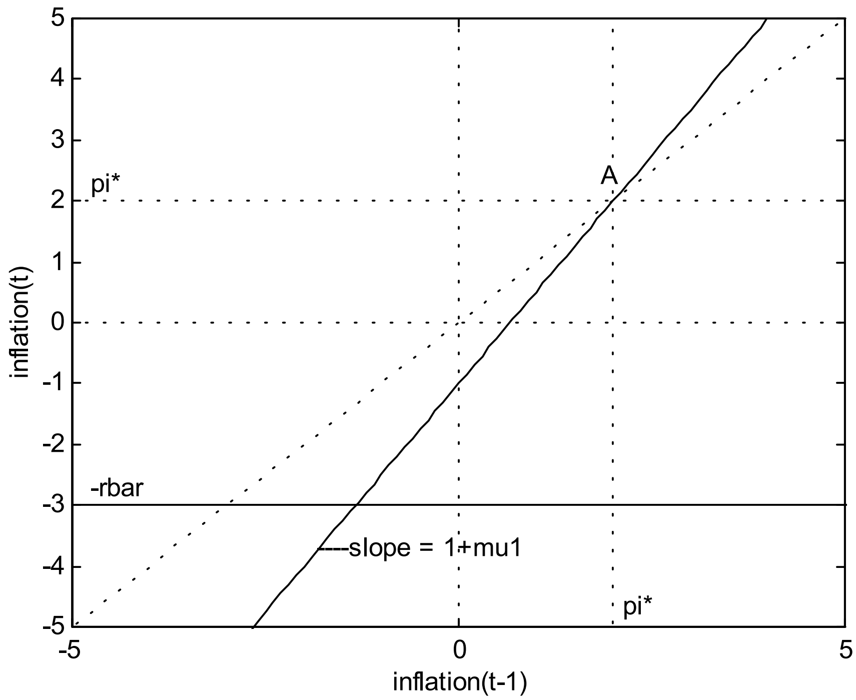


Figure 2

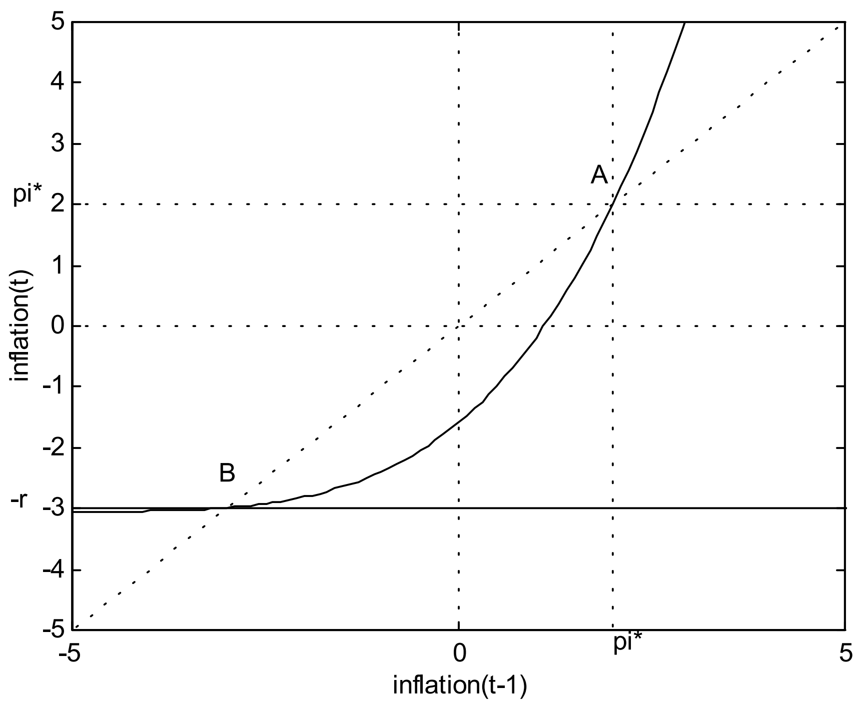
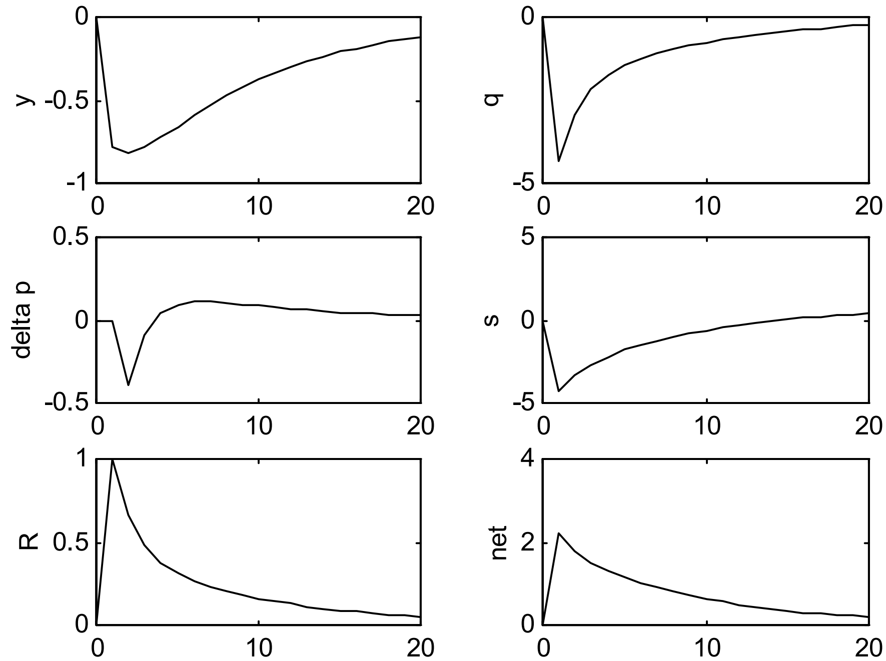
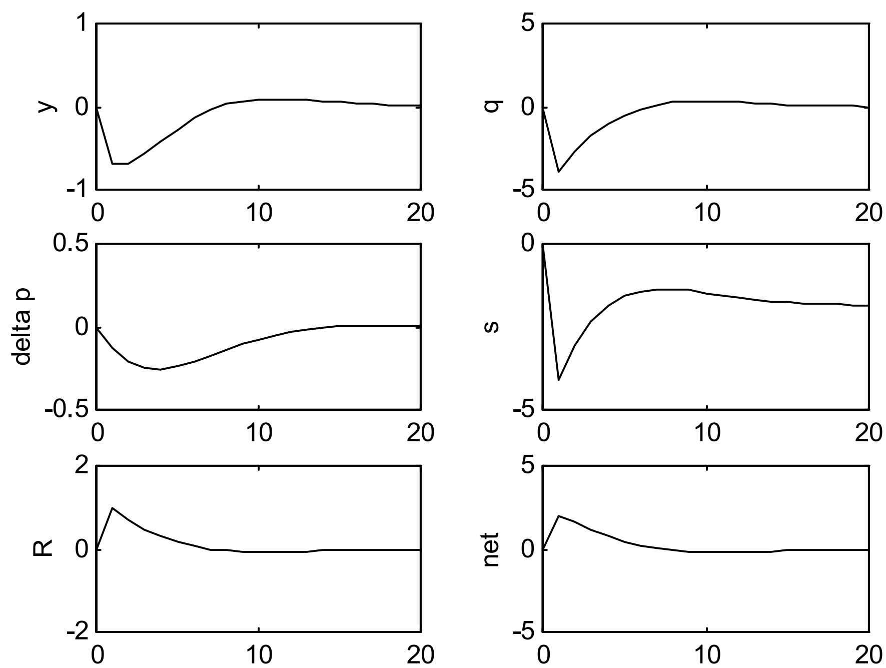


Figure 3

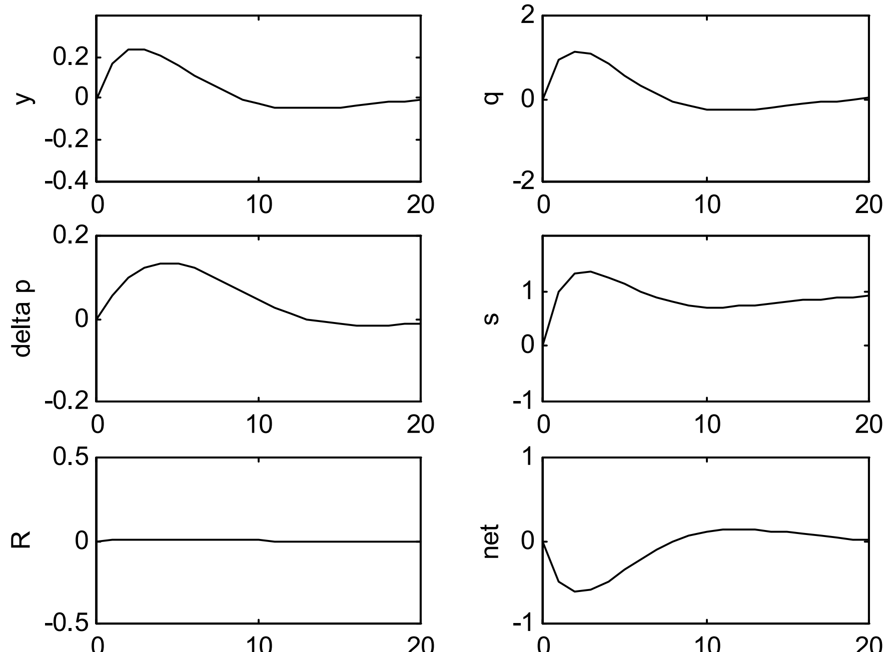


Responses to Unit Shock to Policy Rule, P-Bar Model

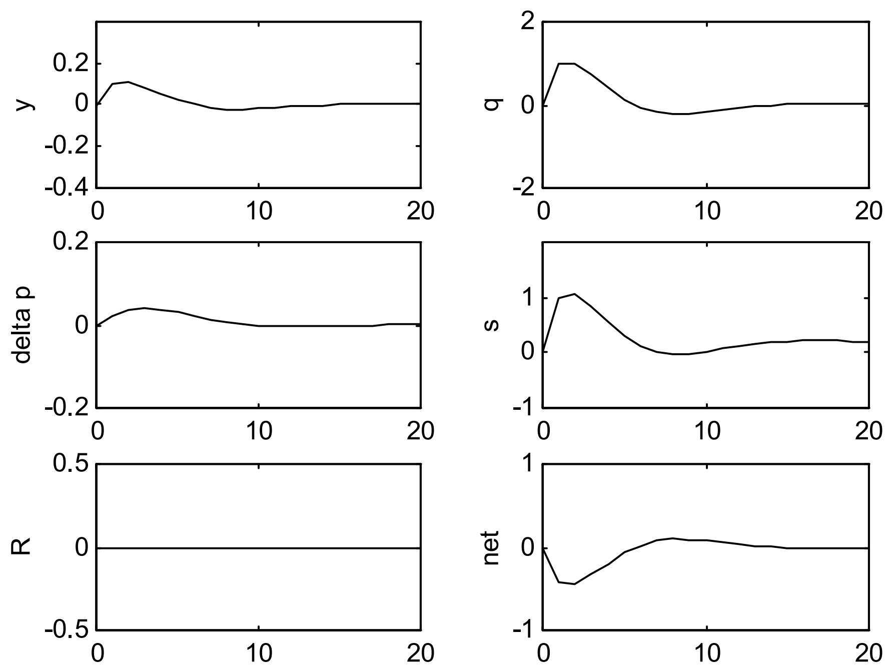


Responses to Unit Shock to Policy Rule, Standard Model

Figure 4

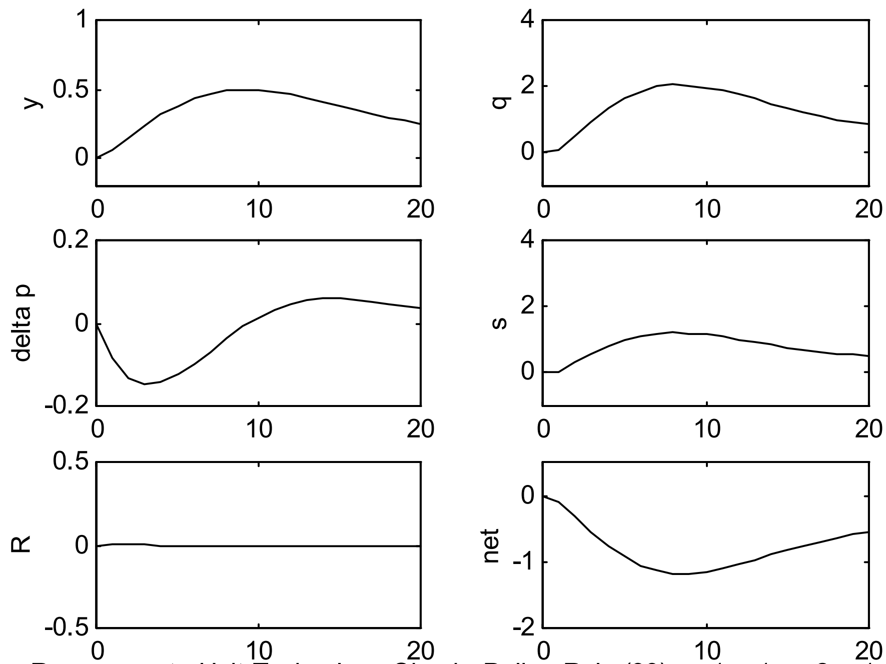


Responses to Unit Shock to Policy Rule (39), nu1 = 1, nu2 = 1

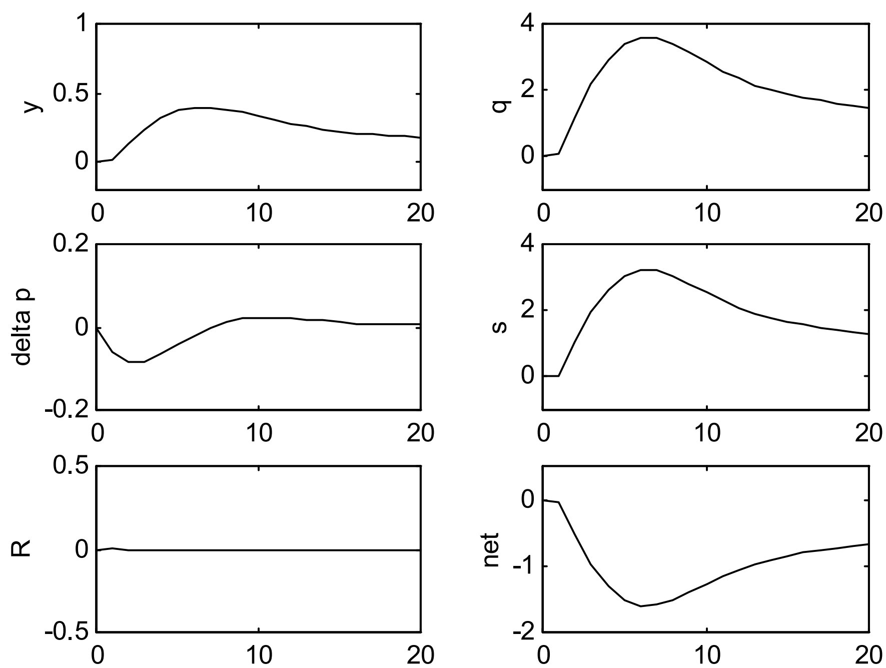


Responses to Unit Shock to Policy Rule (39), nu1 = 10, nu2 = 1

Figure 5



Responses to Unit Technology Shock, Policy Rule (39), nu1 = 1, nu2 = 1



Responses to Unit Technology Shock, Policy Rule (39), nu1 = 10, nu2 = 1

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